BIOMECHANICAL ANALYSIS OF REVERSED SHOULDER PROSTHESIS: BENEFIT OF THE INFERIOR POSITION OF THE GLENOID BASE PLATE

+*Terrier, A; **Farron, A
+*Orthopaedic Research Laboratory, Swiss Federal School of Technology, Lausanne, Switzerland.
**Orthopaedic Hospital, University of Lausanne, Lausanne, Switzerland
alexandre.terrier@epfl.ch

INTRODUCTION

The reversed constrained total shoulder prosthesis is usually proposed for glenohumeral degenerative diseases with a deficient rotator cuff. Although short- and mid-term results for this type of prosthesis were initially encouraging, an important rate of complications is now being reported. One of the main problems seems to be the impingement between the polyethylene cup and the inferior pole of the scapular neck [1]. Various solutions were proposed to avoid the resulting bone notch: change orientation and positioning of the glenoid base plate, improve design of the prosthesis. Since the question remains open, there is still a need to better understand the biomechanics of the reversed prosthesis in order to reduce the failure rate of this implant. Therefore, the goal of this study was to develop a finite element model of the shoulder, and use it to compare two glenoid base plate positions: centered and inferior. The results were compared to a healthy shoulder.

METHOD

A 2D finite element model of the shoulder abduction in the scapular plane was developed. Scapula and humerus geometry was obtained from CT images projected onto the scapular plane. A reversed prosthesis (Aequalis, Tornier S.A.S, Montbonnot, France) was inserted in two different positions: centered and inferior position of the glenoid base plate. Six major muscles were included: middle, anterior, and posterior deltoid, supraspinatus, subscapularis and infraspinatus. The location of muscles origins and insertions were determined from the CT and anatomical observations. Bone and metal parts were assumed rigid, while cartilage and polyethylene were deformable bodies. Muscles were represented by deformable truss elements, with no bending resistance and high tensile stiffness. Muscles-bone contacts and scapulothoracic rhythm were accounted for. Instead of the usual ball-socket approximation, the real joint contact surfaces were used. Abduction and joint stabilization were entirely achieved by the muscles, which were synchronized through a home-made element, implemented into the commercial finite element solver Abaqus (Abaqus, Inc.). Basically, this element assured predefined ratios of the muscles forces, while a shortening of the middle deltoid was imposed. These ratios, relative to the middle deltoid, were set constant during abduction, and estimated from PCSA and EMG. The arm mass was set to 3.7 Kg (5% body weight). Joint and muscles forces were calculated from 0 to 150 degrees of abduction, for the healthy shoulder and with the prosthesis. The reversed prosthesis was tested without the cuff muscles. Impingement between the humerus and the inferior part of the glenoid, but also with the acromion, were evaluated, and the allowed range of motion was estimated.

RESULTS

For the healthy shoulder, the glenohumeral force was maximal at 80 degrees of abduction and reached about 87% of the body weight (fig 1). Without any action of the cuff muscles, and without the prosthesis, an immediate superior subluxation occurred, and prevented therefore abduction. With the reversed prosthesis, abduction was possible even without the cuff muscles. By comparison to the healthy shoulder (A), the force within the glenohumeral joint was 38% lower with the reversed prosthesis in centered position (B) and 46% lower when it was placed in the inferior position (C). Since the muscles forces were assumed to be proportional, only the middle deltoid force is presented. The force within the deltoid was almost unchanged in the centered position, and only 10% lower in the inferior position. For the centered position, abduction was free of impingement only from 32 to 112 degrees. There was impingement between the lower part of the glenoid and the medial part of the prosthesis, but also between the acromion and the lateral part of the humerus. On the other hand, for the inferior positioning of the base plate, the range of free of impingement abduction was 20-143 degrees.

DISCUSSION

For the healthy shoulder, the glenohumeral and muscles forces were in agreement with the literature [2]. This study confirms the benefit of the reversed prosthesis when the cuff muscles are deficient: the constrained shape of the prosthesis substitutes for the missing stabilization function of the cuff, while the medialized rotation center increases the deltoid efficiency, balancing for the missing motory function of the cuff muscles. This study also reveals the impingement problem, not only with the inferior glenoid, but also with the arcomion, which might be related to reported fracture of the acromion and the spine of the scapula. The inferior positioning of the base plate has been proved to partly avoid the impingement and increase the range of motion. Finally, the deltoid force being almost equivalent to the healthy case, this type of prosthesis should only be used with a fully functional deltoid.

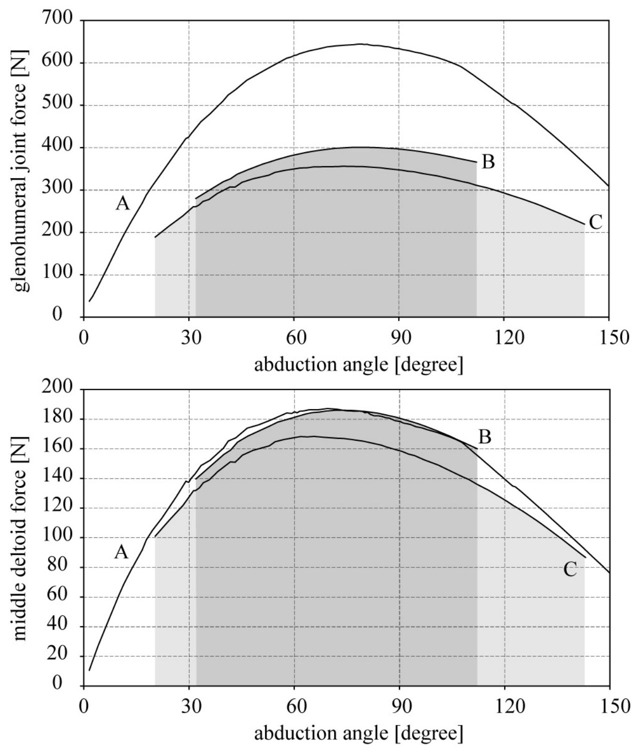

Fig. 1. Force within the glenohumeral joint (top) and the middle deltoid (bottom) for the healthy shoulder (A), the centered reversed prosthesis (B), and the inferior positionning (C). The gray zones correspond to the range of abduction free of impingements (with scapula and acromion).

REFERENCES

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